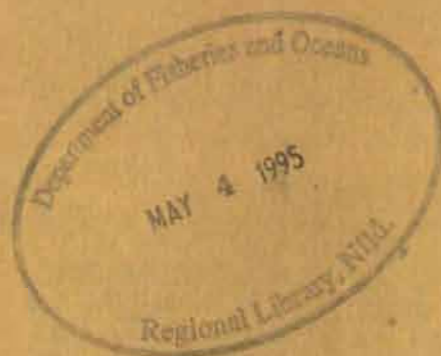# A Study of Cod/Flatfish Separation in Otter Trawls with the use of Rigid Grates

W.M. Hickey, G. Brothers, and D.L. Boulos

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March, 1995

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Canada

Canadian Technical Report of
Fisheries and Aquatic Sciences

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A Study of Cod/Flatfish Separation in Otter Trawls
with the use of Rigid Grates

by

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ABSTRACT

Hickey, W.M., G. Brothers and D.L. Boulos, 1995. A Study of Cod/Flatfish Separation in Otter Trawls with the use of Rigid Grates. Can. Tech. Rep. Fish. Aquat. Sci. 2027: vi + 36.

In June and December of 1993, the ability of rigid grates to reduce the catch of cod (*Gadus morhua*) when directing for american plaice (*Hippoglossoides platessoides*) was studied during two commercial trips to the southern Grand Banks of Newfoundland. Stainless steel grates measuring 1.5 x 1.5m and possessing either a horizontal or vertical bar spacing were evaluated in trawls containing a retainer over the fish outlet to catch escaping fish. Grates assessed with a horizontal bar spacing of 102 or 76mm resulted in almost 100% exclusion of cod but also excluded a large percentage of flatfish. Similar grates with a vertical bar spacing of 127mm, 158mm or 163mm were also assessed and produced indications that a grate's installation angle and fish outlet shape have an influence on the separation of cod and plaice. The best performance from the grate with a 127mm bar spacing resulted in a cod exclusion of 84.4% and a plaice loss of 7.9% while the 163mm bar spacing's best performance produced a cod exclusion of only 52.3% and a plaice loss of 4.2%. The grate with a 158mm bar spacing, unlike the other grates tested, used a small non-commercial mesh size in the codend and retainer which produced a cod exclusion of 58.5% and a plaice loss of 8.6%. These latter results are not characteristic of commercially fished catches as many more small fish would normally have escaped through a larger commercial mesh. Length comparisons between the catch in the codend and retainer indicated that there was generally a difference in the distribution of cod and plaice excluded or caught and these differences were somewhat dependent on the grate that was used.

RÉSUMÉ

Hickey, W.M., G. Brothers, D.L. Boulos, 1993. A Study of Cod/Flatfish Separation in Otter Trawl with the use of Rigid Grates. Can. Tech. Rep. Fish. Aquat. Sci. 2027: vi + 36.

En juin et en décembre 1993, on a étudié la capacité des grilles rigides à réduire les prises de morue (*Gadus morhua*) dans la pêche sélective de la plie canadienne (*Hippoglossoides platessoides*) au cours de deux sorties de pêche commerciale dans le sud des Grands Bancs de Terre-Neuve. À ces occasions, on a évalué des grilles d'acier inoxydable de 1,5 m x 1,5 m, possédant des barreaux soit verticaux soit horizontaux et placées dans des chaluts dont l'orifice d'évasion avait été muni d'un filet de retenue pour capturer le poisson qui s'échappait. Les grilles à barreaux horizontaux espacés de 102 ou de 76 mm ont permis d'exclure près de 100 % de la morue, mais également un fort pourcentage de poissons plats. Dans l'évaluation de grilles semblables dotées de barreaux verticaux espacés de 127, 158 ou 163 mm, il s'est avéré que l'angle d'installation de la grille et la forme de l'orifice d'évasion du poisson ont une influence sur la séparation de la morue et de l'aiglefin. C'est la grille à barreaux espacés de 127 mm qui a produit les meilleurs résultats, soit l'exclusion de la morue dans une proportion de 84,4 % et une perte de 7,9 % des plies, tandis que la grille à espacement de 163 mm n'a permis d'exclure que 52,3 % de la morue tout en occasionnant une perte de 4,2 % de plies. Quant à la grille dont les barreaux étaient espacés de 158 mm, contrairement aux autres grilles essayées, elle était installée avec un cul-de-chalut et un filet de retenue à petit maillage non commercial ayant abouti à l'exclusion de 58,5 % des morues et à la perte de 8,6 % des plies. Les résultats produits par cette grille ne sont pas caractéristiques des prises commerciales, car davantage de petits poissons se seraient normalement échappés d'un filet à plus grandes mailles. Les comparaisons de longueur entre les prises du cul-de-chalut et celles du filet de retenue dénotaient une différence générale dans la répartition des morues et des plies exclues ou capturées, différence qui dépendait dans une certaine mesure de la grille utilisée.

Introduction

The southern Grand Banks have traditionally been an area where american plaice (*Hippoglossoides platessoides*) are commercially fished year round. By-catches from this fishery have been known to vary across locations and time of year but regularly include differing amounts of yellowtail (*Limanda ferruginea*), greysole (*Glyptocephalus cynoglossus*) and cod (*Gadus morhua*). With the present low levels of the atlantic cod stocks and the implementation of a low cod by-catch quota, methods have been actively sought to ensure that catches of by-catch species (particularly cod) are in line with their respective quotas.

Efforts to exclude non-targeted fish species from otter trawls have been ongoing globally for many years. These pursuits have resulted in a variety of strategies being devised, several of which have proved to be successful. One of the more notable methods, the Nordmore grate (Isaksen, 1990), has been shown to successfully exclude the by-catch of many fish species in both the Norwegian (Isaksen et al., 1990) and Canadian (Hickey et al., 1993; Cooper and Hickey, 1991) shrimp fisheries. In Canada, the adaptation of a rigid grate to separate silver hake from groundfish has also proven to be a viable method of by-catch exclusion (Cooper, 1992). Many other initiatives that have attempted to make otter trawls more species selective have produced mixed results. Horizontal separator panels are one such example. When installed in otter trawls in the U.K., these panels have shown some success with separating and effecting the release of haddock and whiting when directing for cod and plaice (Main and Sangster, 1982). However, these positive results were only obtained during experimental trials. Furthermore, the

complicated design and installation requirements for this panel have discouraged its commercial acceptance.

Following proposals from FPI, two co-operative studies were conducted on the southern Grand Banks using the commercial vessel the "Newfoundland Hawk". These studies, conducted in June and December of 1993, were aimed at reducing the ratio of cod to flatfish taken when directing for plaice. While this cod by-catch has been known to be as much as 70% of the catch, the objective of these studies was to reduce this catch of cod to approximately 20% and still maintain a high flatfish yield. An earlier study (Hickey et al., 1995) that was conducted in 1992 evaluated large square mesh codends and horizontal separator panels as a means of meeting this objective. This second study evaluates rigid grates with either horizontal bars (76, 102 and 150mm bar spacings) or vertical bars (127, 163 and 152mm bar spacings). Moreover, to further determine the optimal rigid grate configuration, the grate's performance at different installed angles and with either a triangular or rectangular fish outlet were tested. The following report focuses on this evaluation of rigid grates and their effectiveness in reducing the by-catch and the cod by-catch in particular, when fishing for plaice on the southern Grand Banks.

Materials and Methods

The "Newfoundland Hawk", a 48 meter stern trawler that is owned and operated by FPI, was used for two 10-day experimental fishing trips to NAFO sub-division 3LNO on the southern Grand Banks (Figure 1). This vessel normally engages in plaice fishing and utilized its regular 96 model bottom trawl (Figure 2) which contained rockhopper footgear and 8 m^2 Morgere trawl doors. The headrope was 29.3m in length and it contained 55 plastic floats that were 20.0cm in diameter. Footrope length was 30.5m and it used rubber discs that were 40.6cm in diameter. The bridle and ground warp lengths were 45.7m and 128.0m, respectively. Mesh size was 162mm in the wings, 143mm in the body (i.e. square and belly) and 125mm in the lengthening piece. The codend and retainer mesh sizes differed over the two trips and will be mentioned in the sections pertaining to each trip.

All tests were performed while the vessel was commercial fishing and this was conducted on a 24-hour schedule. An underwater video camera system was carried on each trip and was used to observe fish behaviour as well as assist with fine tuning the set-up of experimental gear (Figure 3). The camera was situated to view fish in contact with the grate as well as escaping through the fish outlet and as such, a retainer was not used during these sets. Each stainless steel grate (Figure 4) measured 1.5 x 1.5 meters, possessed either horizontal or vertical bars and was installed in a section of the lengthening piece for easy installation and removal. When positioned in the codend, each grate contained eighteen floats that neutralized its weight in the water. These floats were 20.3cm in diameter and were attached such that 8 were located on the top frame of
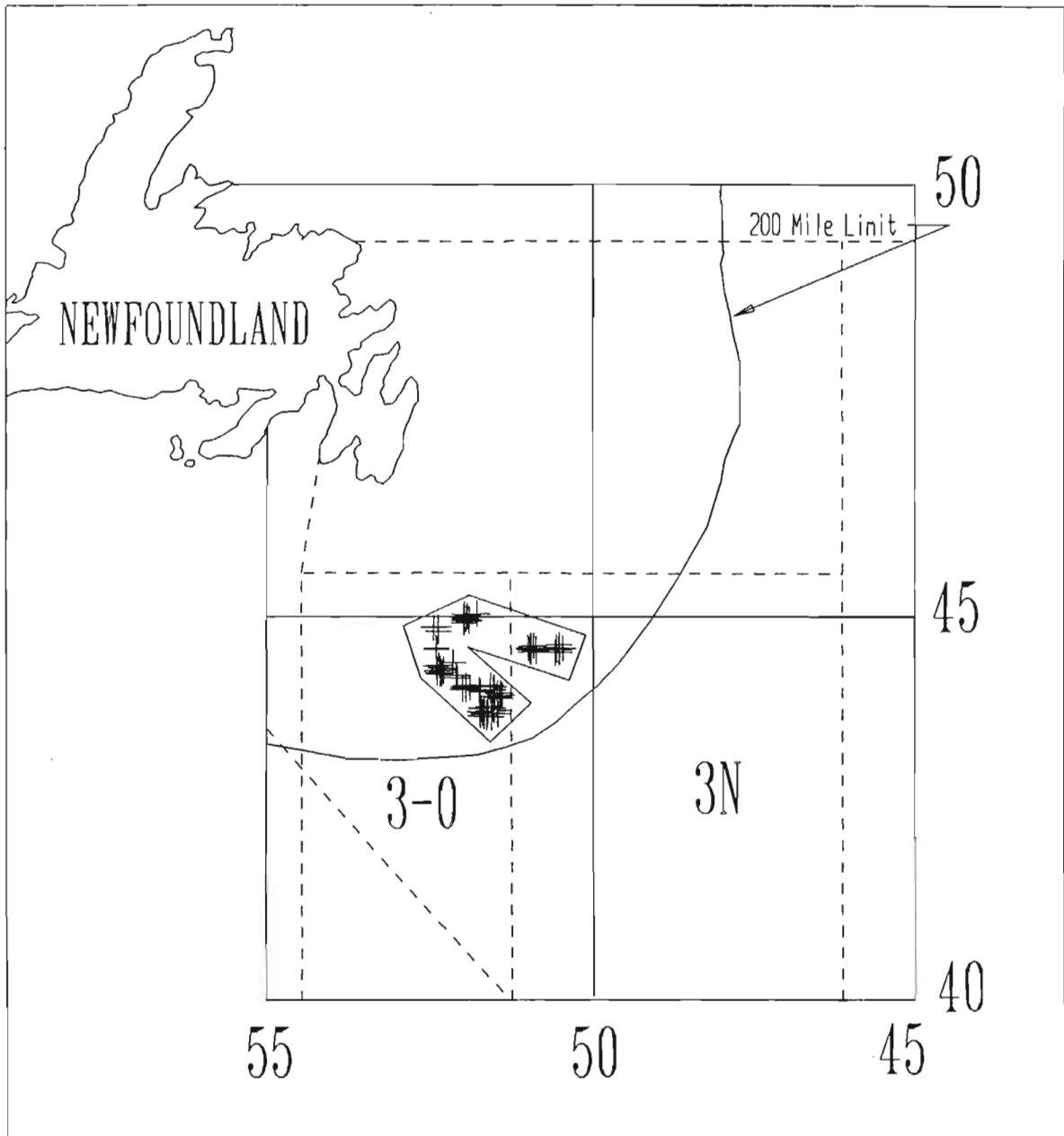
Figure 1: A Map of the Area on the Southern Grand Banks where the Rigid Grates were Evaluated.

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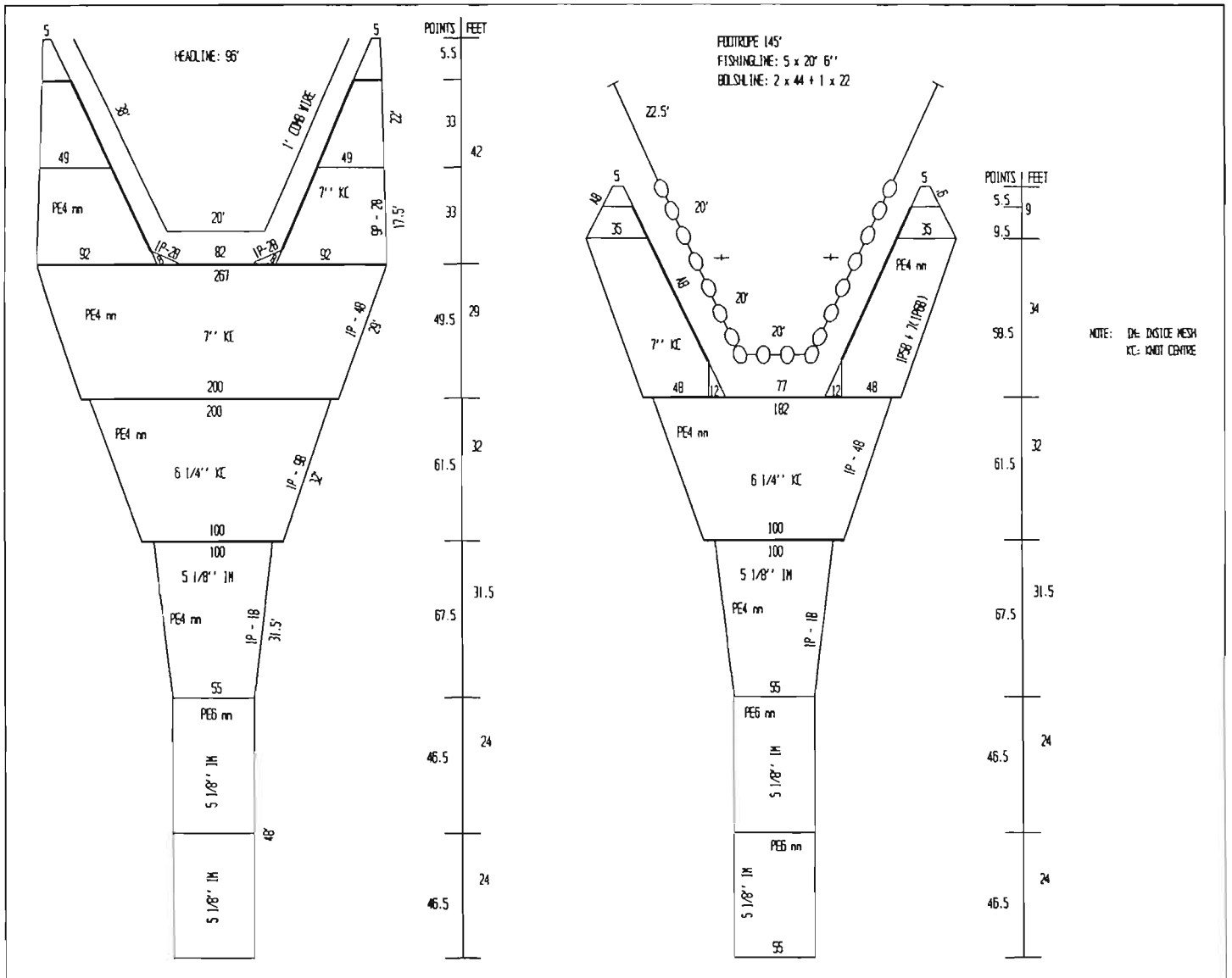
Figure 2: The Schematic for a 96 Model Bottom Trawl.

Retainer

Retainer Frame

Rigid Grate

Codend

COD/FLATFISH SEPARATION GRATE

Floats

Fish Outlet

Guide Panel
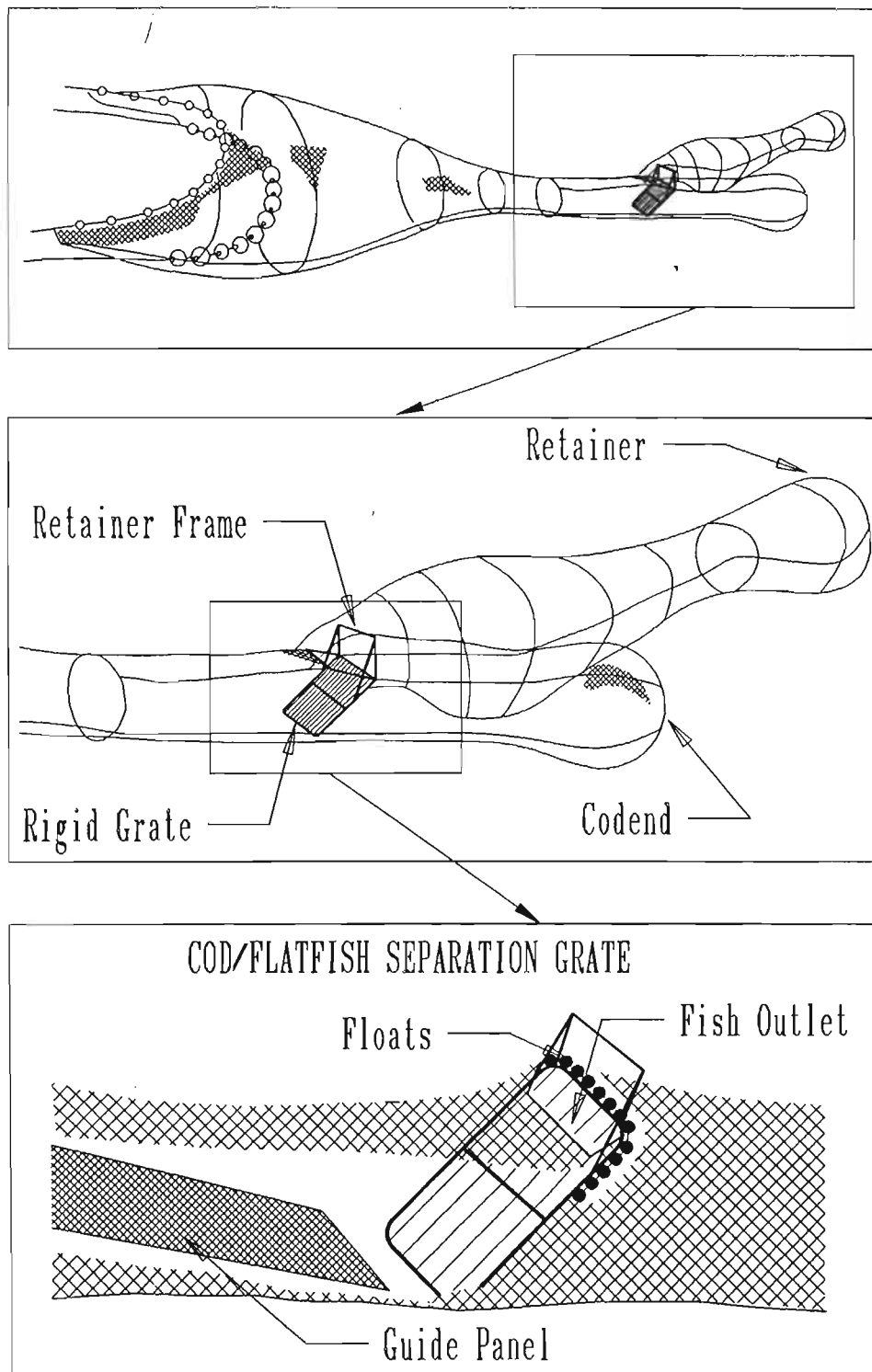
Figure 3: A Diagram of the Placement and Set-up for Rigid Grates. Notice the Rectangular Fish Outlet and the Retainer Frame.
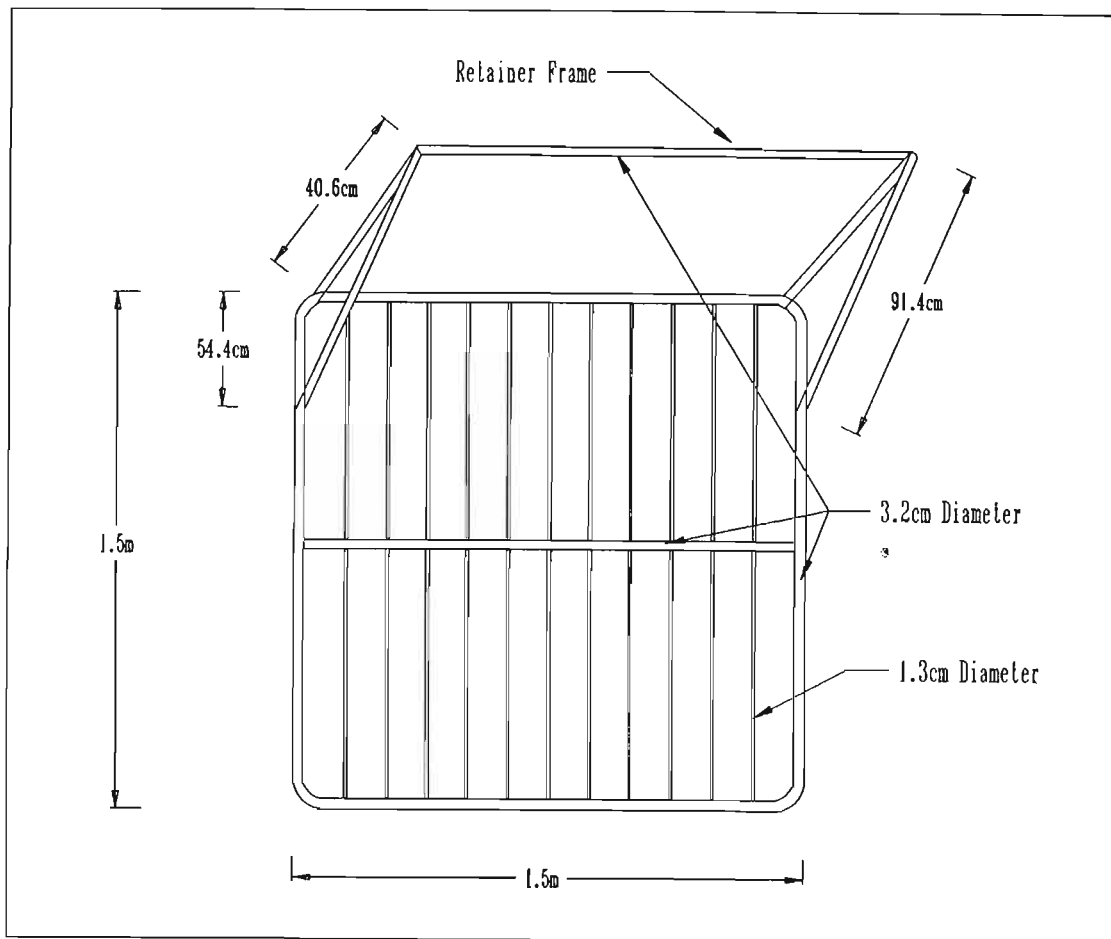
Figure 4: Rigid Grate Bar Sizes and Dimensions (not to scale) that were used During this Study.

the grate and 5 were placed on each side. A rectangular guiding panel was used to direct the catch towards the lower section of the grate. This panel was installed in front of the grate and consisted of an 84mm mesh size.

A number of modifications to the set-up of the experimental gear were evaluated during the two trips. These modifications were aimed at determining whether the optimal performance of these grates is achieved with the same grate angle of 50° and triangular fish outlet which have

been assessed as optimal for reducing the by-catch in shrimp trawls. Over the course of the two trips, the installed grate angle was either $50°$, $58°$ or $67°$ and the fish outlet was changed from a triangular opening with a base of 25 meshes at the grate and a height of 12.5 meshes to a roughly rectangular opening which consisted of a length of 25 meshes at the grate that extended 2 meshes out where the outlet's length was reduced to 21 meshes. Support ropes were attached to the top corners of each grate and extended to a point on the selvedge. These ropes were originally intended for use in maintaining the grate angle but were later used to change the angle quickly without having to reinstall the grate.

TRIP 1: RIGID GRATES WITH HORIZONTAL OR VERTICAL BARS

A self contained video camera system was assembled and mounted on the trawl to observe the fish outlet during the first trip. This system consisted of a video recorder, power pack, halogen light and Benthos 4204 mini-colour underwater video camera. Mechanical problems were encountered with the operation of the underwater camera and very little video footage was obtained. A scanmar acoustic monitoring system with angle, waterflow, height and spread sensors was also used to record the placement and operation of the experimental gear. A retainer bag, positioned over the fish outlet, was used during a number of sets and allowed losses, expected when commercial fishing, to be determined. The codend consisted of a mesh size of 131mm and the retainer, when used, contained a mesh size of 137mm. Both the codend and retainer consisted of a nominal 140mm mesh size.

A total of 44 sets were performed during this first trip:

1) The first fourteen sets were used to determine the best procedures for deploying and retrieving the experimental gear, to evaluate gear modifications and to observe fish and gear behaviour with the underwater camera. These sets used grates possessing horizontal bars, an installed grate angle of 50° and a triangular fish outlet. The first two of these sets used a grate with bars spaced at 102mm while the remaining 12 sets used a grate with bars spaced at 150mm.

2) The next eight sets were performed evaluating rigid grates with horizontal bars and a triangular fish outlet that was enclosed with a retainer. Seven of these sets used a grate with bars spaced at 102mm and an installed grate angle of 58°. Only one set was performed with a grate that contained bars spaced at 76mm and an installed grate angle of 67°.

3) Eighteen sets were conducted using rigid grates with vertical bars spaced at 127mm and included a retainer bag over the fish outlet. Nine of these sets used a triangular fish outlet and an installed grate angle of 67°, 7 used a rectangular fish outlet and an installed grate angle of 67° and 2 used a rectangular fish outlet with an installed grate angle of 58°.

4) Four sets were conducted using a rigid grate with vertical bars spaced at 163mm and a retainer over the fish outlet. Three of these were performed with an installed grate angle of 67° and a rectangular fish outlet while 1 set used an installed grate angle of 58° and a rectangular fish outlet that was moved 8 meshes away from the grate.

TRIP 2: A RIGID GRATE WITH VERTICAL BARS SPACED AT 152mm

During the second trip, a remotely operated camera vehicle (i.e. "Mermaid Explorer") with an Osprey model OE1323 SIT camera was used to observe the trawl. Mechanical and electrical problems were also experienced with this system, however, several hours of video were obtained recording plaice and yellowtail in contact with the grate. The grate used on this trip contained vertical bars spaced 152mm apart and was modified with the addition of a frame (Figure 4) to the top of the grate. This retainer frame was constructed to keep the retainer bag approximately 41cm above the grate and thus avoid the possibility of masking the fish outlet. While masking was not observed during the first trip, the frame was constructed merely as a precautionary measure. A rectangular fish outlet and an installed grate angle of 58° was used with each set performed. The 58° angle was a compromise between the higher angles found to be most effective on the first trip and the increased blockage that was associated with the larger grate angles used during the first trip.

A total of 28 sets were performed with this grate possessing vertical bars such that:

1) Seventeen sets were performed using a codend with a mesh size of 131mm mesh. This permitted the underwater camera to be used in viewing both the performance of the grate as well as fish in contact with it.

2) Eleven sets were performed using a nominal 40mm mesh size in the codend and retainer. This enabled all the fish encountered by this system to be collected and thus further evaluate the effectiveness of this grate with a vertical bars spaced 152mm apart.

During both trips, catches from all successful sets were separated by species and random samples of 300 to 500 fish were taken. Measurements included weights and lengths of the cod

and flatfish (i.e. plaice, yellowtail and greysole) caught within this sample as well as the total catch weights for other by-catch species. Length measurements consisted of fork length for cod and total length in the case of the flatfish species. When the retainer bag was used, catches from it and the codend were each sampled separately. Bridge data was also collected for duration, position, time and water depth that was encountered over the course of each set. All gear modifications and damage that may have resulted were recorded, as was the scanmar sensor readings when it was used. Only successful sets were evaluated, sets resulting in gear damage were not used.

A nested ANOVA design (Montgomery, 1991) was used to compare length measurements of the excluded (i.e. in the retainer bag) and non-excluded (i.e. in the codend) fish for each grate as well as the main species caught during the first trip. This analysis compared fish lengths among the different grates used as well as between the codend and retainer within the sets of each grate possessing sufficient numbers in both the codend and retainer. A similar nested ANOVA design was also used with the second trip to compare length distributions between the codend and retainer of each set that possessed sufficient numbers of the main species being assessed. A significance level of 0.05 was used for all ANOVA tests and any pairwise length comparisons that were conducted between the retainer and codend of a set were performed using Bonferroni's procedure (Neter et al., 1985) with a similar significance level of 0.05. The length selectivity of the grate with a bar spacing of 152mm was to be determined, however, the fish exposed to this grate did not possess a sufficient length range to determine a selectivity relationship.

RESULTS

The first trip to the southern Grand Banks took place over June 12 to 27 of 1993 and the second was conducted over December 5 - 12 of the same year (Table 1). Set durations ranged from 2 to 3½ hours and towing speeds were consistently at 3 knots. The by-catch of each set contained a significant amount of skate (*Raja radiata*, mainly), in some cases, it represented a larger portion of the catch than did american plaice. Other by-catch species, which represented a minor component of the total catches, included wolffish (*Anarhichas lupus*, mainly), white hake (*Urophycis tenuis*), atlantic halibut (*Hippoglossus hippoglossus*), monkfish (*Lophius americanus*), lumpfish (*Cyclopterus lumpus*) and capelin (*Mallotus villosus*).

Trip #1: Rigid Grates with Vertical or Horizontal

This trip resulted in forty-four sets being performed in water depths ranging from 75 to 103 meters. The first 14 sets used horizontal bars (Table 1) and resulted in plaice catches that were low when compared to other vessels fishing the same area. These low catches indicated that further investigations should be directed towards grates with bars spaced above 102mm (and possibly above 150mm), if horizontal bars are to be effective in reducing the cod by-catch. Mechanical problems were encountered with the operation of the underwater camera during these sets and as such, efforts to monitor the grates' actual performance were unsuccessful.

Two of the 14 sets were performed with a 102mm bar spacing and resulted in a total catch of 803 and 1427kg for all species caught in each of the two sets. Cod accounted for 75kg in the catch of these combined sets while plaice, yellowtail and greysole accounted for 256kg,

Table 1: A Summary of the Riggings used with each Rigid Grate System Tested on Both Trips.

Cruise #	Date	Grate		Grate Angle		Fish Outlet Shape	Set Number	Mesh Size (mm)	
		Orientation	Bar Spacing (mm)	Initial	Measured (Mean)			Codend	Retainer Bag
1	June 12-13	Horizontal	102	50°	-	Triangular	1-2	131	-
1	June 13-15		150	50°	-		3-14	131	-
1	June 15-21		102	58°	54.5°		15,16 & 18-22	131	137
1	June 22		76	67°	66.7°		23	131	137
1	June 24	Vertical	127	67°	-		24-32	131	137
1	June 24-25			67°	65.4°	Rectangular	33-38	131	137
1	June 26		163	67°	-		39,41 & 42	131	137
1	June 26			58°	-	Rectangular*	43	131	137
1	June 27		127	58°	78.5°	Rectangular	44,45	131	137
				67°	-		47	131	137
2	December 5-7	Vertical	152	58°	-		1-8	131	-
2	December 7-8			58°	-		9-12	40	40
2	December 8-11			58°	-		13-21	131	-
2	December 12			58°	-		22-28	40	40

* The fish outlet was moved 8 meshes (1.07m) forward of the grate.

448kg and 452kg, respectively. The percentage of cod in the catch of each set was either 1.4 or 4.5%. A grate with horizontal bars spaced at 150mm was used for the twelve remaining sets which resulted in a total catch of 15015kg for all species and this varied from 302 to 2560kg over the individual sets. This total catch contained 1008kg of cod, 2822kg of plaice, 2816kg of yellowtail and 1641kg of greysole with cod representing from 0 to 20.5% by weight of all species taken. The skate by-catch was quite large at 7323kg and ranged from 45 to 1452kg. Problems experienced with the use of these rigid grates included the occasional deformation and blockage which occurred when large quantities of skate were encountered. This blockage, identified by the water flow sensor reading, was usually cleared by alternately reducing and increasing speed.

GRATES WITH HORIZONTAL BARS

Eight sets were obtained (Table 1) evaluating two rigid grates (102mm and 76mm bar spacings) that possessed horizontal bars and a triangular fish outlet. Seven of these sets were made with a grate of 102mm bar spacing that was installed at 58° and had a total catch of 10402kg for all species in both the codend and retainer. This catch ranged from 291 to 2437kg for individual sets. Within the total catch cod represented 1324kg, plaice 2567kg, yellowtail 2254kg and greysole 767kg (Table 2). There was a large skate by-catch at 3374kg which varied from 21 to 1185kg over the 7 sets. The catch in the codend of all sets that used this grate included 25kg of cod, 1781kg of plaice, 1393kg of yellowtail and 512kg of greysole which corresponds to a loss/exclusion (by weight) of 98.1%, 30.6%, 38.2% and 33.2%, respectively (Figure 5). This high cod exclusion is reflected in the amount of cod caught out of the 4 main

Table 2: A Catch Summary for the Various Grate Riggings that were used on Trip 1.

| GRATE ORIENTATION		HORIZONTAL		VERTICAL				
BAR SPACING (mm)		102	76	163		127		
NUMBER OF SETS		7	1	3	1	9	2	7
FISH OUTLET SHAPE		Triangular	Triangular	Rectangular	Rectangular (Moved)	Triangular	Rectangular	Rectangular
GRATE ANGLE (MEAN)		54.5°	66.7°	-	-	-	78.5°	65.4°
SPECIES	Location	Catch (kg)	Catch (kg)	Catch (kg)	Catch (kg)	Catch (kg)	Catch (kg)	Catch (kg)
COD	Codend	25	3	1057	258	348	15	270
	Retainer	1299	61	1161	327	3232	84	2007
	Total	1324	64	2218	585	3580	99	2277
	% Exclusion	98.1	95.3	52.3	55.9	90.3	84.8	88.1
PLAICE	Codend	1781	363	1544	800	5315	970	4353
	Retainer	786	301	68	140	1056	83	410
	Total	2567	664	1612	940	6371	1053	4763
	% Loss	30.6	45.3	4.2	14.9	16.6	7.9	8.6
YELLOWTAIL	Codend	1393	227	331	164	2127	1588	1871
	Retainer	861	215	13	82	419	129	209
	Total	2254	442	344	246	2546	1717	2080
	% Loss	38.2	48.6	3.8	33.3	16.5	7.5	10.0
GREYSOLE	Codend	512	165	673	340	1450	468	1105
	Retainer	255	121	17	20	203	35	81
	Total	767	286	690	360	1653	503	1186
	% Loss	33.2	42.3	2.5	5.6	12.3	7.0	6.8
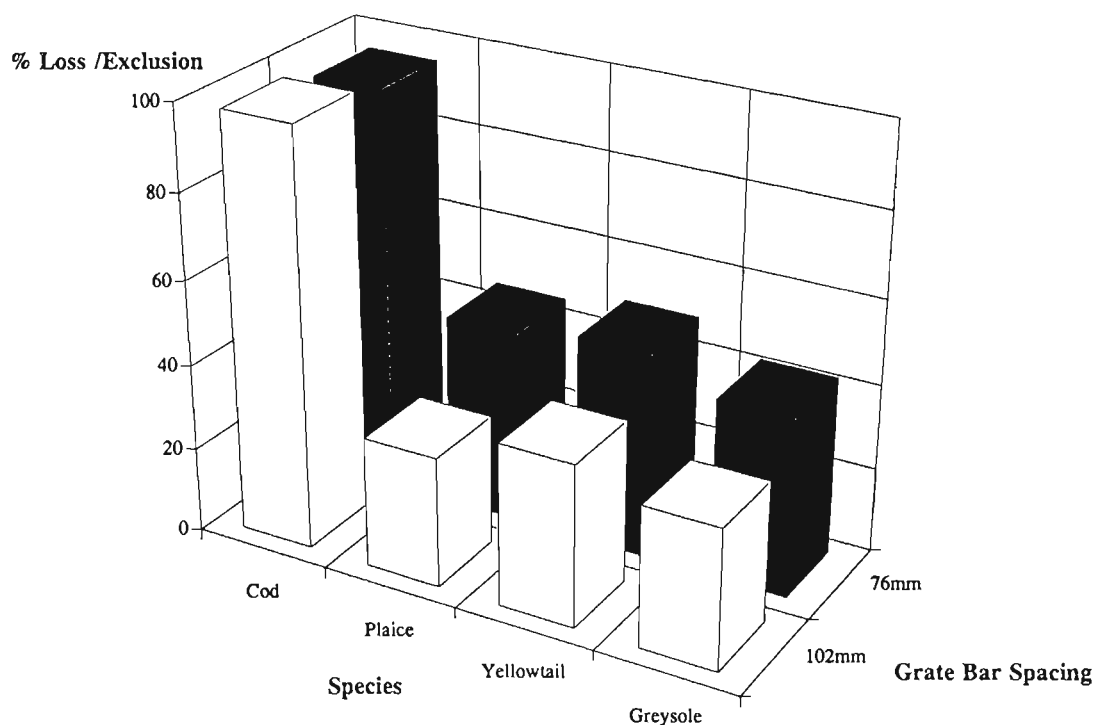
Figure 5: The Loss/Exclusion Percentages (by weight) for each of the Four Main Species Evaluated when using Rigid Grates with Horizontal Bars.

species evaluated (i.e. cod, plaice, yellowtail and greysole). Cod represented only 0.7% of the main species caught in the codend, as opposed to 19.2% that were taken in both the codend and retainer combined. This provides a comparison between the actual catch of cod among the main species and the expected catch of cod that would result if a grate had not been used.

The single set using the grate with a bar spacing of 76mm that was installed at an angle of 67° contained a total catch of 2616kg. This catch included 64kg of cod, 664kg of plaice,

442kg of yellowtail and 286kg of greysole (Table 2). A skate by-catch of 1143kg was obtained from this set. The portion of this catch within the codend contained 3kg of cod, 363kg of plaice, 227kg of yellowtail and 165kg of greysole which is associated with a loss/exclusion of 95.3%, 45.3%, 48.6% and 42.3%, respectively (Figure 5). Usage of this grate reduced the percentage of cod taken within the codend from an expected 4.4%, as was obtained in both the codend and retainer, to 0.4% of the main species evaluated. While the amount of cod in the catch was reduced by both grates, flatfish losses were quite high and as such, attention was switched to the use of grates with vertical bars.

GRATES WITH VERTICAL BARS

Twenty-two sets (Table 1) were obtained evaluating two rigid grates (127mm and 163mm bar spacings) possessing vertical bars and various riggings. Nine of these sets were made using a 127mm bar spacing on a grate installed at an angle of 67° and with a triangular fish outlet. The total catch consisted of 19824kg for all species taken in both the codend and retainer and the catch for each set varied from 1225 to 5152kg. This total catch contained 3580kg of cod, 6371kg of plaice, 2546kg of yellowtail and 1653kg of greysole (Table 2). The total skate by-catch was 5037kg and it varied from 320 to 1343kg over the individual sets. Within the codend, the catch contained 348kg of cod, 5315kg of plaice, 2127kg of yellowtail and 1450kg of greysole which corresponds to a loss/exclusion of 90.3%, 16.6%, 16.5% and 12.3%, respectively (Figure 6). Usage of this grate reduced the percentage of cod among the main species caught to 3.8% within the codend, as compared to 25.3% within both the codend and retainer. As can be seen, the cod exclusion with this grate appears to be fairly good but the flatfish loss was a little high.
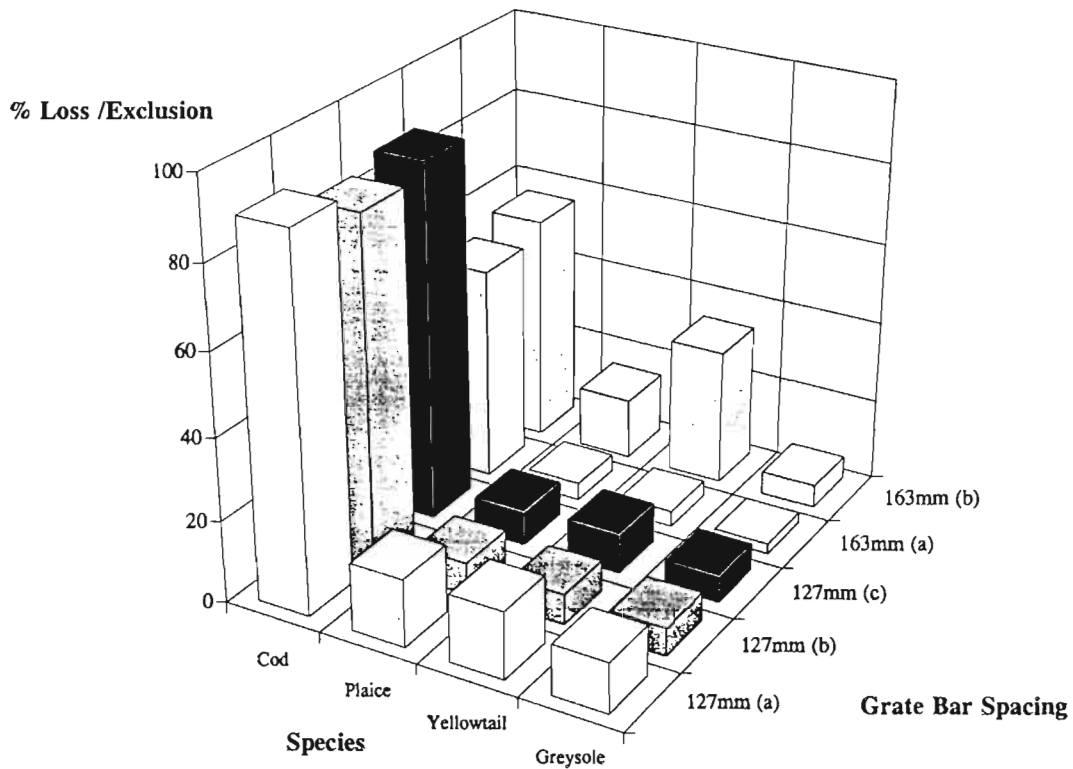
Figure 6: The Loss/Exclusion Percentages (by weight) for each of the Four Main Species Evaluated when using the Rigid Grates with Vertical Bars Spaced at 127mm or 163mm. The Grates were Rigged such that 127mm(a) was Installed at 67° and used a Triangular Fish Outlet, 127mm(b) was Installed at 58° and used a Rectangular Fish Outlet, 127mm(c) was Installed at 67° and used a Rectangular Fish Outlet, 163mm(a) was Installed at 67° and used a Rectangular Fish Outlet while 163mm(b) was Installed at 58° and used a Rectangular Fish Outlet that was moved from its regular position.

Seven sets were made using a rectangular fish outlet with the same grate (i.e. 127mm bar spacing) and installed angle (i.e. 67°). These sets produced slightly improved results over the previously tested riggings. A total catch of 15941kg was obtained for all species in both the codend and retainer while the catch for each set ranged from 1641 to 2818kg. Cod accounted for 2277kg with plaice, yellowtail and greysole accounting for 4763kg, 2080kg and 1186kg, respectively (Table 2). The skate by-catch was 5195kg and this varied from 247 to 1308kg over the individual sets. The catch within the codend contained 270kg of cod, 4353kg of plaice, 1871kg of yellowtail and 1105kg of greysole which has an associated loss/exclusion of 88.1%, 8.6%, 10.0% and 6.8%, respectively (Figure 6). Cod represented 3.6% of the four main species caught in the codend as compared to 22.1% within both the codend and retainer, the expected catch of cod if this grate had not been used. The cod exclusion as well as the percentage of cod within the codend were similar when either a rectangular or a triangular outlet was used but the flatfish loss was reduced when using the rectangular outlet.

Two sets were made with a bar spacing of 127mm in a grate installed at 58° and using a rectangular fish outlet. This rigging produced results fairly similar to the previous one that used the same grate with a rectangular outlet and 67° installed angle. It should be noted that the mean grate angle for these 2 sets was measured at 78.5°, which places this grates' rigging closer to an installed angle of 67°, as opposed to the required angle of 58°. The total catch for all species taken during each of these sets was either 2308kg or 1514kg. Cod accounted for 99kg of the catch in both sets while plaice, yellowtail and greysole accounted for 1053kg, 1717kg and 468kg, respectively. The loss/exclusion was 84.8% for cod, 7.9% for plaice, 7.5% for yellowtail and 7.0% for greysole (Figure 6). Cod represented 0.5% of the main species within

the codend, as opposed to 2.9% within both the codend and retainer, the expected catch if this grate had not been used.

Three sets were performed with a grate that used vertical bars spaced 163mm apart, a 67° installation angle and a rectangular fish outlet. These sets resulted in a total catch of 9646kg for all species within the codend and retainer. Catches for individual sets ranged from 2191 to 3992kg. Cod accounted for 2218kg of the catch, while plaice, yellowtail and greysole each represented 1612kg, 344kg and 690kg, respectively (Table 2). The total skate by-catch was 4421kg and this varied from 962 to 1861kg over the individual sets. Cod represented 1057kg within the codend while plaice, yellowtail and greysole accounted for 1544kg, 331kg and 673kg, respectively. The loss/exclusion was 52.3% for cod, 4.2% for plaice, 3.8% for yellowtail and 2.5% greysole (Figure 6). Within the codend, cod accounted for 29.3% of the four main species caught. This cod percentage was reduced from 45.6% of the main species taken in both the codend and retainer.

A single set was made with the same grate, a 163mm bar spacing, installed at 58° and using a rectangular fish outlet that was moved from its normal position. This set produced poor and unexpected results. While the catch weighed 3385kg for all species caught in both the codend and retainer, skate accounted for 1216kg. Cod represented 585kg of the catch whereas plaice, yellowtail and greysole represented 940kg, 246kg and 360kg, respectively (Table 2). The codend contained 258kg of cod, 800kg of plaice, 164kg of yellowtail and 340kg of greysole which corresponds to a loss/exclusion of 55.9%, 14.9%, 33.3% and 5.6%, respectively (Figure 6). Although this rigging produced a cod exclusion similar to that for the previous one which used the same 163mm bar spacing, flatfish losses rose dramatically when the fish outlet was

moved from its normal position. Cod accounted for 16.5% of the four main species caught within the codend and 27.5% in both the codend and retainer, the expected catch if this rigging was not used.

COMPARISONS OF THE FISH SIZES LOST AND CAUGHT

In comparing the length distributions within the catch of each grate evaluated on this first trip, it was found that similar distributions of cod (F=0.939, p=0.4410), plaice (F=2.892, p=0.0638), yellowtail (F=1.696, p=0.2014) and greysole (F=1.168, p=0.3622) were caught within the combined catch of both the codend and retainer when the different grates were tested. This result indicates that each grate caught a similar length distribution of each species evaluated. However, when comparing the distributions caught within the codend and retainer of each grate used, a significant difference in the distribution was determined for both cod (F=65.34, p<0.0001) and plaice (F=12.46, p<0.0001). There was no significant difference between the codend and retainer for either yellowtail (F=1.52, p=0.0520) or greysole (F=1.26, p=0.1896) length distributions with any set performed.

When using the grate with a horizontal bar spacing of 102mm, cod tended to be larger in the retainer with a mean length of 99.5cm for all sets, as compared to 48.2cm in the codend. This difference was determined to be significant for all but one of the sets assessed. The mean length of cod caught during the single set which used the grate with a horizontal bar spacing of 76mm was 43.8cm in the retainer and 52.3cm in the codend, however, this tendency for cod to be larger in the codend was determined not to be statistically significant.

The two rigid grates with vertical bars (127mm and 163mm bar spacings) behaved similarly with the cod lengths each excluded (retainer bag catch) or caught (codend catch).Both these grates tended to catch larger cod in the codend regardless of their rigging. The grate which used a 127mm bar spacing installed at 67° with a triangular fish outlet caught cod that possessed a mean length of 89.8cm in the codend and 44.7cm in the retainer over all sets combined. This difference was determined to be significant for all but one of these sets which used a triangular fish outlet. Similarly, usage of a rectangular fish outlet with this same grate and installed grate angle resulted in larger cod being caught in the codend when compared with the retainer and this difference was determined to be statistically significant for each set assessed. Combined, these sets with the rectangular outlet resulted in a mean cod length of 76.2cm in the codend and 44.4cm in the retainer. Furthermore, when a rectangular fish outlet and installed grate angle of 58° were used with this same grate, cod were again significantly larger in the codend of each set. Cod possessed a mean length of 52.6cm in the codend and 37.7cm in the retainer for the combined sets.

As previously mentioned, the grate with a 163mm bar spacing that was installed at 67° and used a rectangular fish outlet also resulted in larger cod being caught in the codend. This difference was statistically significant for each set assessed. The mean cod lengths caught in the retainer and codend were similar to those for the 127mm bar spacing with a mean of 83.5cm in the codend and 44.8cm in the retainer for the sets combined.

Plaice tended to be larger in the retainer when each of the four grates (horizontal or vertical bars) were used. However, this difference between the codend and retainer was never significant for any of the sets that used the grate with a horizontal bar spacing of 76mm or a

vertical bar spacing of 163mm. The grate possessing horizontally spaced bars of 102mm contained a mean of 39.3cm in the codend and 40.2cm in the retainer for the combined sets. This slight difference was more pronounced for one unusual set and it was found to be statistically significant.

The 127mm vertically spaced bars produced the largest plaice length differences between the codend and retainer. Using this grate with an installed angle of 67° and a triangular fish outlet resulted in a mean plaice length of 39.9cm in the codend and 44.3cm in the retainer over the combined sets. This difference was statistically significant for all but one of the sets assessed. However, usage of a rectangular outlet and a 67° installed grate angle with this same grate resulted in only one set possessing larger plaice in the retainer. The mean lengths for the combined sets with this rigging were 42.1cm in the codend and 44.9cm in the retainer. Plaice caught with a grate using a 127mm bar spacing, installed angle of 58° and rectangular fish outlet resulted in no significant length differences between the codend and retainer of any set performed.

Trip # 2: A Rigid Grate with Bars Spaced at 152mm

The second trip to the Grand Banks resulted in 28 sets being conducted (Table 1) in water depths ranging from 53 to 84m. All these sets used the same grate, grate angle and fish outlet. Mechanical problems were again encountered with the camera's operation but some useful footage was obtained. One particular set showed very little blockage of this grate with a 152mm bar spacing and resulted in a large percentage of the flatfish being observed to pass through the grate and into the codend. During this two hour set, less than 10 flatfish were observed to escape

and when retrieved, it yielded a plaice catch of 1.5 tonnes. Seventeen sets were made without a retainer and contained a total catch of 32989kg for all species caught. The catch for individual sets varied from 511 to 3540kg. Cod accounted for 772kg of the total while plaice, yellowtail and greysole each represented 5787kg, 18096kg and 53kg, respectively. The skate by-catch was 8157kg for the combined sets and ranged from 46 to 1500kg over the individual sets. As with the first trip, deformation and blockage were occassionally observed and it was largely attributed to encounters with large quantities of skate.

Eleven sets were made with a small mesh codend and retainer. The total catch for both codend and retainer was 15255kg for all species taken and this ranged from 315 to 2690kg for individual sets. The total catch contained of cod, 1847kg of plaice, 9016kg of yellowtail and 160kg of greysole (Table 3). The skate by-catch was 2875kg for the combined sets and for individual sets, this ranged from 21 to 400kg. Cod accounted for 512kg within the small mesh codend while plaice, yellowtail and greysole accounted for 1689kg, 7608kg and 146kg, respectively. These numbers correspond to a loss/exclusion of 58.5% for cod, 8.6% for plaice, 15.6% for yellowtail and 8.8% for greysole (Figure 7). It should be noted that both the codend and retainer consisted of small mesh which did not allow any fish to escape and as such, the exclusions are more indicative of the split of fish encountered rather than the contents in a typical catch. Out of the four main species caught, cod accounted for 5.1% of these in the codend, 31.4% in the retainer and 10.1% in both the codend and retainer. This result for cod is largely a reflection of the small numbers encountered (n=383), especially since many cod were of non-commercial sizes (Figure 8) and would have escaped through a commercial mesh size (i.e. 140mm).

Table 3: A Catch Summary for the Grate Rigging used during Trip 2.

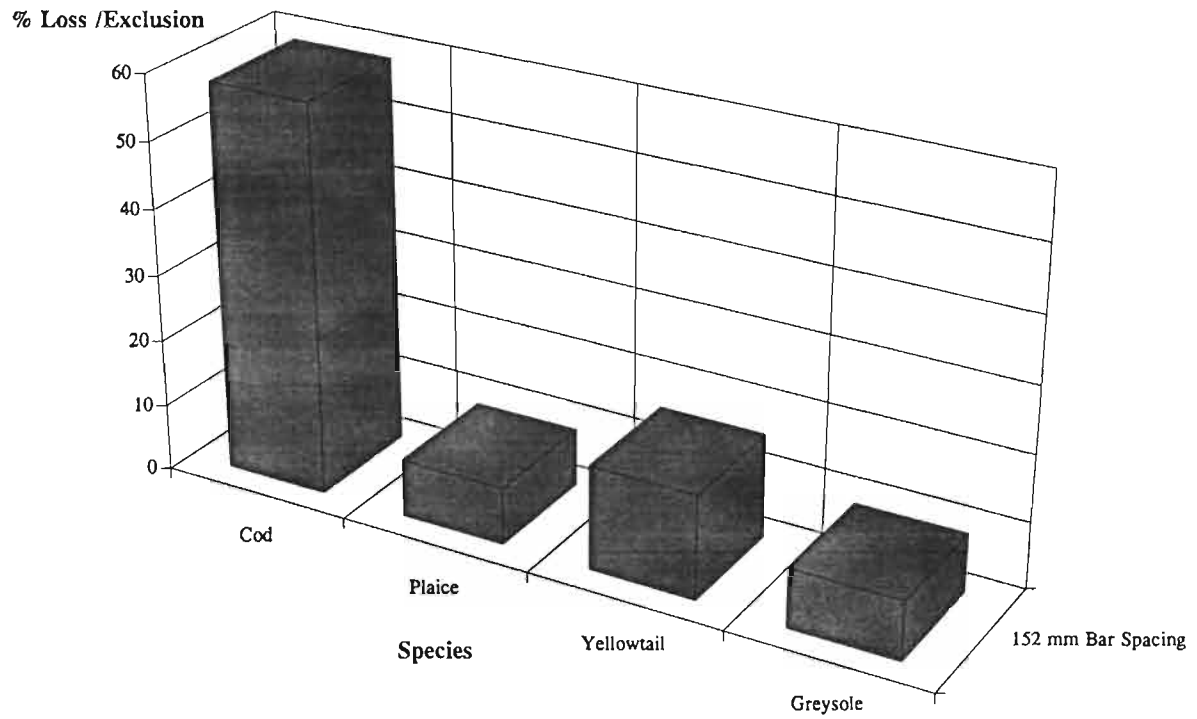| GRATE ORIENTATION		VERTICAL
BAR SPACING (mm)		152
NUMBER OF SETS		11
FISH OUTLET SHAPE		Rectangular
GRATE ANGLE (INSTALLED)		58°
SPECIES	Location	Catch (kg)
COD	Codend	512
	Retainer	722
	Total	1234
	% Exclusion	58.5
PLAICE	Codend	1689
	Retainer	158
	Total	1847
	% Loss	8.6
YELLOWTAIL	Codend	7608
	Retainer	1408
	Total	9016
	% Loss	15.6
GREYSOLE	Codend	146
	Retainer	14
	Total	160
	% Loss	8.8

Figure 7: The Loss/Exclusion Percentages (by weight) for each of the Four Main Species Evaluated when using the Rigid Grate with a Vertical 152mm Bar Spacing on Trip 2.
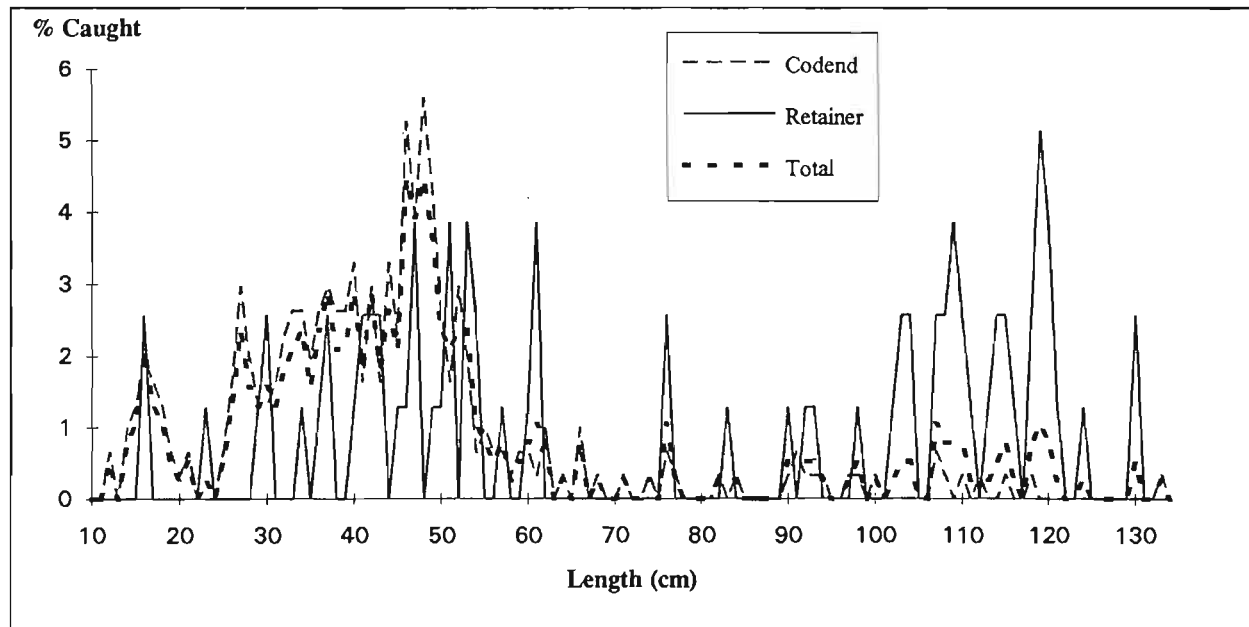
Figure 8: The distribution of cod caught within the small mesh retainer, codend and both combined when using a grate possessing a vertical bar spacing of 152mm that was installed at a 58° angle and utilized a rectangular fish outlet.

COMPARISONS OF THE FISH SIZES LOST AND CAUGHT

The length distributions contained in each of the codend and retainer were found to differ significantly for cod (F=27.58, p<0.0001), plaice (F=6.21, p<0.0001) and yellowtail (F=8.32, p<0.0001) within at least one of the sets assessed. In the case of yellowtail and plaice, the retainer tended to contain fish of slightly greater length with a mean of 35.8cm and 35.7cm, respectively, as compared to the codend which contained a mean of 34.4cm for yellowtail and 31.7cm for plaice over all sets. The trend for cod was reversed with a tendency for larger fish to be captured in the codend. Considering all sets, the codend contained a mean cod length of 44.3cm and the retainer contained a mean of 35.8cm. These differences between the codend and

retainer were found to be significant for six of nine sets in the case of cod, five of eleven sets for plaice and four of eleven sets for yellowtail. No comparisons were made for greysole due to the small numbers caught over all sets.

The results for cod appear to reflect the predominating small fish sizes that were encountered (Figure 8). Since many of these fish would have normally escaped a larger commercial mesh size, the cod exclusion would probably be different. It appears that while larger plaice and larger yellowtail tend to be excluded by the grate, this difference is not very pronounced. Furthermore, plaice (Figure 9) and yellowtail (Figure 10) entering the codend tend to reflect, almost identically, the distributions of these species that were encountered. This indicates that while larger flatfish are more likely to be excluded than are smaller flatfish, the numbers affected are not very high.
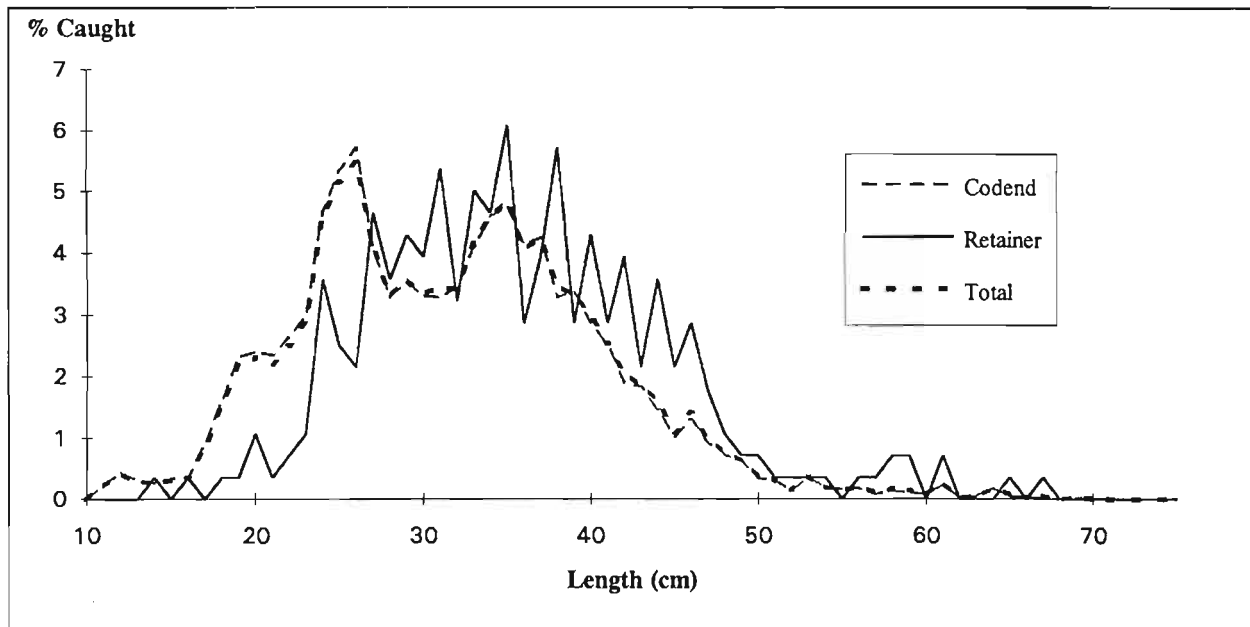
Figure 9: The distribution of plaice caught within the small mesh retainer, codend and both combined when using a grate possessing a vertical bar spacing of 152mm that was installed at a 58° angle and utilized a rectangular fish outlet.
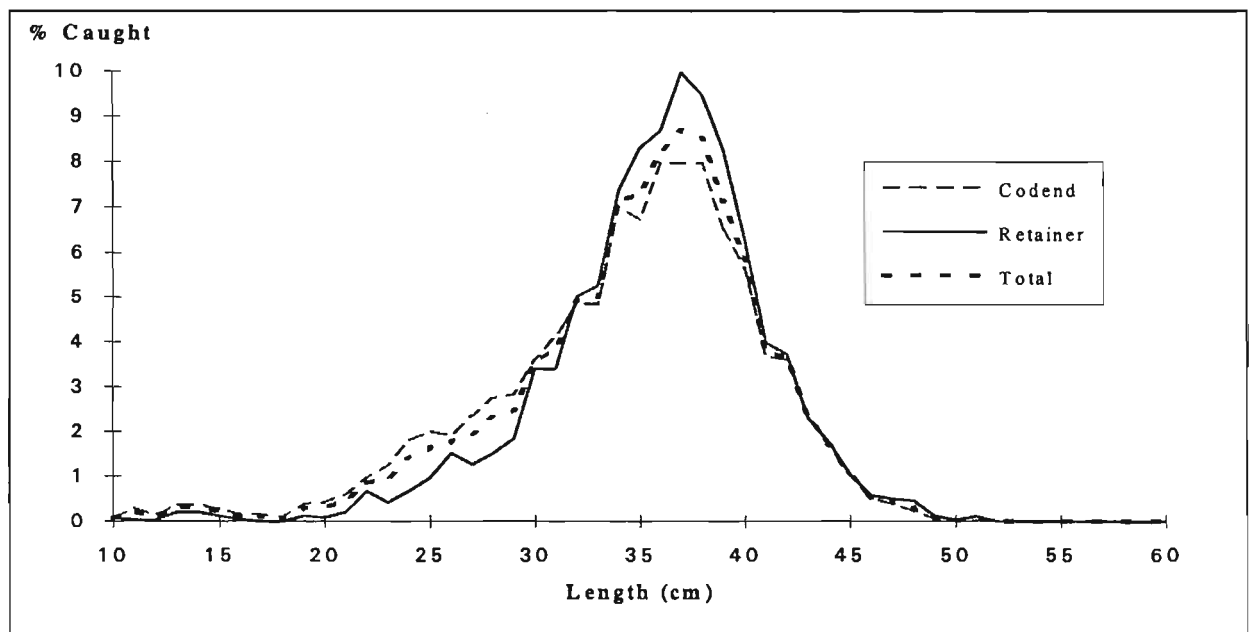

Figure 10: The distribution of yellowtail caught within the small mesh retainer, codend and both combined when using a grate possessing a vertical bar spacing of 152mm that was installed at a 58° angle and utilized a rectangular fish outlet.

DISCUSSION

In this study, it has been shown that the use of rigid grates possessing either horizontal or vertical bars can substantially reduce the by-catch of cod when directing for flatfish. Grates with horizontal bars of 102 or 76mm bar spacing were shown to exclude almost 100% of the cod that would normally be caught without the use of a grate. While the horizontal bars excluded large amounts of cod and reduced the percentage in the catch to less than 1%, these grates had an undesirable affect on flatfish. Plaice, yellowtail and greysole losses were all high and comparable when horizontal bars were used. Losses with each of these grates tended to range from roughly 35% with the 102mm bar spacing to roughly 45% with the 76mm bar spacing. The lengths of cod and plaice that were excluded by the horizontal bars were, in most instances, found to be significantly different from the lengths that were caught in the codend. These differences were such that excluded cod were generally larger with both bar spacings and excluded plaice tended to be smaller with the 102mm bar spacing. This would appear to indicate that the grates tested with horizontally spaced bars would not be an appropriate means of excluding cod and still maintain a high plaice or flatfish yield. However, grates with horizontal bars spaced wider than 102mm may produce more favourable results since it was noticed that the loss of flatfish decreased and cod exclusion was relatively constant (i.e. almost 100%) when the bar spacing was increased from 76 to 102mm.

Of the grates tested, vertically spaced bars tended to produce much better results than the horizontal ones. When using the 127mm vertical bar spacing, cod exclusion was always above 85%. While this grate reduced the percentage of cod among the main species (i.e. cod, plaice,

yellowtail and greysole) within the catch to less than 5%, the mean length of these cod in the codend were significantly larger than the cod that were excluded. The loss of flatfish was moderate, generally around 10% in most sets and only excluded plaice tended to be significantly larger than what was caught in the codend. This loss was reduced when a rectangular fish outlet was used, rather than a triangular one, and the cod excluded was found to remain relatively unchanged. In a number of sets using a rectangular fish outlet, the grate angle was increased. This change resulted in a reduction of the flatfish loss while having little affect on the exclusion of cod. This indicates that both a rectangular fish outlet shape and a grate angle greater than $50°$, an angle typically used with rigid grates, would not hinder cod exclusion and possibly minimize flatfish loss.

The use of a rectangular fish outlet shape with an installed grate angle of $67°$ was tested with a 163mm vertical bar spacing. This grate produced a minimal loss of flatfish, less than 5% for each of plaice, yellowtail and greysole. However, compared to the results with a 127mm bar spacing, the larger 163mm spacing also reduced the cod excluded to only a little over 50%. The percentage of cod among the main species within the total catch was as high as 45.6% but was only reduced to roughly 30% of the catch with use of this grate. Only the excluded cod was found to be significantly smaller than the cod within the codend, as there was no significant difference for the other species assessed. This would indicate that a vertical bar spacing in between 127mm and 163mm may produce an optimal cod and flatfish separation and thus lower the percentage of cod in the catch below 30%.

In an effort to evaluate the effect of the fish outlet position, the rectangular fish outlet used during one set with the 163mm bar spacing was moved 8 meshes forward of the grate. In

comparison to the sets performed with the fish outlet in the regular position, the cod excluded increased slightly and the flatfish loss increased dramatically, almost 10-fold in the case of yellowtail. This was surprising as the exclusion of all species was expected to drop and suggests that such a move in the fish outlet position would be ineffective with improving the separation of cod and flatfish.

A 152mm vertical bar spacing, in between the bar spacing of the two previously tested grates with vertical bars, was expected to produce results closer to the optimal separation of cod and flatfish. However, the skate blockage and small non-commercial mesh size used are believed to have unfavourably influenced the results by increasing the loss\exclusion of both the flatfish and cod beyond what would normally be expected during commercial fishing. Approximately 60% of cod were excluded with this grate, reducing the percentage of cod among the main species within the catch to 5.1%. The cod encountered were generally small and many would be expected to escape through a commercial mesh size. Excluded cod tended to be significantly smaller than what was caught in the codend while the excluded yellowtail and plaice tended to be significantly larger. Flatfish losses were similar to what was determined for the grate with vertical bars spaced at 127mm and in the case of yellowtail, the loss was a little higher with the 152mm spacing. Video observations indicated that this grate performed much better when a commercial mesh size was used and skate blockage was not encountered. From the video footage obtained when this blockage did not occur, it was noticed that very few flatfish were excluded and yields were quite good.

Considering all the sets which showed a significant difference in the length of fish excluded and caught, it would appear that the large vertical bar spacings tested exclude smaller

cod and in some cases, larger flatfish from the catch. This implies that these grates are less selective for larger cod, as more of these tend to pass through the grate and enter the codend. The trend was partially reversed with the horizontal bars that were tested, as larger cod and larger flatfish were excluded by these grates which exemplifies the more typical selection process. Although large flatfish do appear to be excluded by all the grates tested, in most situations the numbers lost tend to be small. The length frequencies of the encountered and partitioned catch, in the case of the grate with a 152mm bar spacing, have indicated that the distributions of the plaice and yellowtail caught tend to mimic the distributions encountered. As previously stated, this would indicate that while larger flatfish tend to be excluded, the numbers of larger flatfish excluded are not very high. Large grate angles in conjunction with a rectangular fish outlet appear to give better results than the traditional set-up, however, caution is suggested as larger grate angles appear to be more susceptible to blockage. In any case, rigid grates with vertically spaced bars between 127mm and 163mm or possibly horizontal bars spaced greater than 102mm would appear to produce the optimal separation of cod and flatfish.

Grate blockage was occassionally encountered and this depended on the abundance of skate and the level of the flatfish catches. While this blockage was found to increase the flatfish losses, it may be possible to reduce this loss with a redesign or removal of the guiding panel and/or possibly by introducing a mechanism to prevent skate from blocking the grate. The grates were found to be easily damaged, usually when contacting the ramp. This damage was largely a result of the wide bar spacing which resulted in a weakened grate structure. An increase in frame and bar diameter is a possible way of alleviating this problem and is recommended for any future experimental or commercial use of these grates. The effectiveness of these grates in areas

containing many small cod is unknown as all sets which employed a commercial mesh size were performed in areas containing mainly large to medium sized cod. It is possible that a combination of grates and large square mesh codends may be required to achieve the same reduction of cod in such areas.

As a testament to the effectiveness of these grates, FPI fitted each of its 27 vessels with rigid grates possessing 140mm vertically spaced bars immediately following the first trip. These vessels were used when fishing in areas with traditionally high levels of cod by-catch. Moreover, this enabled the fleet to operate with a higher flatfish/cod ratio and resulted in the company catching a larger portion of its flatfish quota (Pers. Comm.).

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